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Twenty-two Year Results of a Scots Pine (*Pinus sylvestris* L.) Provenance Test in North Dakota

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Twenty-two Year Results of a Scots Pine (*Pinus sylvestris* L.) Provenance Test in North Dakota

Richard A. Cunningham[1]
Research Geneticist
USDA Agricultural Research Service

David F. Van Haverbeke[2]
Research Forester
Rocky Mountain Forest and Range Experiment Station

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A provenance test of 49 seed sources of Scots pine (*Pinus sylvestris* L.) from eastern Europe, Russia, and Siberia was established in two plantations in north-central North Dakota. After 22 years, trees from seed sources within the region bounded by 20° to 57° east longitude and 50° to 58° north latitude were taller, and larger in diameter, and had denser crowns and greener winter foliage. Total height at age 5 and age 10 was highly correlated with total height at age 22, indicating that selection at an early age (5–10 years) may be possible in Scots pine breeding programs.

Keywords: windbreaks, shelterbelts, seed sources, varieties, selection, crown density, winter foliage color, geographic variation, *Pinus sylvestris* L.

[1]*Cunningham is at the Northern Great Plains Research Laboratory, Mandan, ND.*
[2]*Van Haverbeke, now retired, was formerly at the Forestry Sciences Laboratory, Lincoln, NE. Station headquarters is in Fort Collins, CO in cooperation with Colorado State University.*

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Application

Scots pine is well suited for conservation plantings in the northern Great Plains if planting stock is grown from seed collected in native stands located within the region bounded by 20° to 57° east longitude and 50° to 58° north latitude.

Introduction

The choice of pine species suitable for farmstead, field windbreak, or wildlife habitat plantings and adapted to the northern Great Plains, has generally been limited to ponderosa pine (*Pinus ponderosa* Dougl. ex Laws), and Scots pine (*P. sylvestris* L.). Jack pine (*P. banksiana* Lamb.) and red pine (*P. resinosa* Ait.) have been planted in limited numbers. Poor survival and slow growth are common complaints concerning the use of pine in the northern Great Plains. Genetic variation within most pine species offers the potential for countering these problems because fast growing, well-adapted provenances have been identified for a range of planting sites in the Great Plains (Read 1983; Van Haverbeke 1986a, 1986b).

Studies on the performance of Scots pine in the Great Plains region of North America have reported significant variation among provenances in survival, growth rate, crown density, winter foliage color, winter injury, stem crook, and cone production (Stoeckeler and Rudolf 1949; Cram and Brack 1953; Read 1971; Cunningham 1973; Van Haverbeke 1975, 1986b).

The performance of Scots pine in north-central North Dakota was first reported by Stoeckeler and Rudolf (1949). Following unusual weather conditions in North Dakota in 1946 through 1948, Scots pine from Finnish seed sources showed no browning of foliage, while trees from other seed sources suffered varying degrees of needle discoloration. Generally trees from more northerly sources had less damage than those from southerly seed sources. Cunningham (1973) reported on the first extensive provenance test of Scots pine in North Dakota. A provenance test of 49 seed sources from eastern Europe, Russia, and Siberia was established at three locations in North Dakota and one in Nebraska. After 10 years (7 in Nebraska), trees from 50° to 55° latitude and 20° to 40° longitude survived best, were taller, and had greener winter foliage. Several provenances appeared to be suitable for planting in shelterbelts and for Christmas trees. This paper reports the 22-year (33 seed sources) and 20-year (16 seed sources) performance of these same 49 seed sources in two plantations in north-central North Dakota.

Materials and Methods

Test Plantation Establishment

Seed collection, planting stock production and plantation establishment were previously documented (Cunningham 1973). Briefly, planting stock of 24 seed sources, supplied by the Lake States Forest Experiment Station in 1959, was lined out in transplant beds at the North Dakota Forest Service nursery in Towner. Nine additional seed sources of 2–0 stock supplied by the Petawawa Forest Experiment Station, Chalk River, Ontario, Canada were lined out in transplant beds at Towner Nursery in 1960. In the spring of 1961, both groups of trees were hand planted at Denbigh Experimental Forest (48° N. lat., 100° W. long., elevation 453 m) in north-central North Dakota (trial 1).

Single-tree plots were planted in 24 replications of a randomized, complete block design. Each test tree was separated by filler trees of ponderosa pine from a Black Hills, South Dakota seed source. Spacing was 2.1 m by 2.1 m.

The original study was extended in 1963 by the acquisition of 16 additional seed sources from western Europe and eastern Asia. In 1961, Jonathan Wright, Michigan State University, sent 2–0 seedlings of these 16 seed sources to the Institute of Forest Genetics at Rhinelander, Wisconsin. The seedlings were lined out in transplant beds until April 1963, when they were lifted and sent to the USDA Forest Service Shelterbelt Laboratory, Bottineau, North Dakota. These additional seed sources were planted in the spring of 1963 at the Denbigh Experimental Forest (trial 2). Ten replications of square, 4-tree plots were planted at a spacing of 2.1 m x 2.1 m. Plantation failures were replanted with extra line-out stock in the spring of 1964. The geographic location of the 49 seed sources tested in trials 1 and 2 are shown in figure 1.

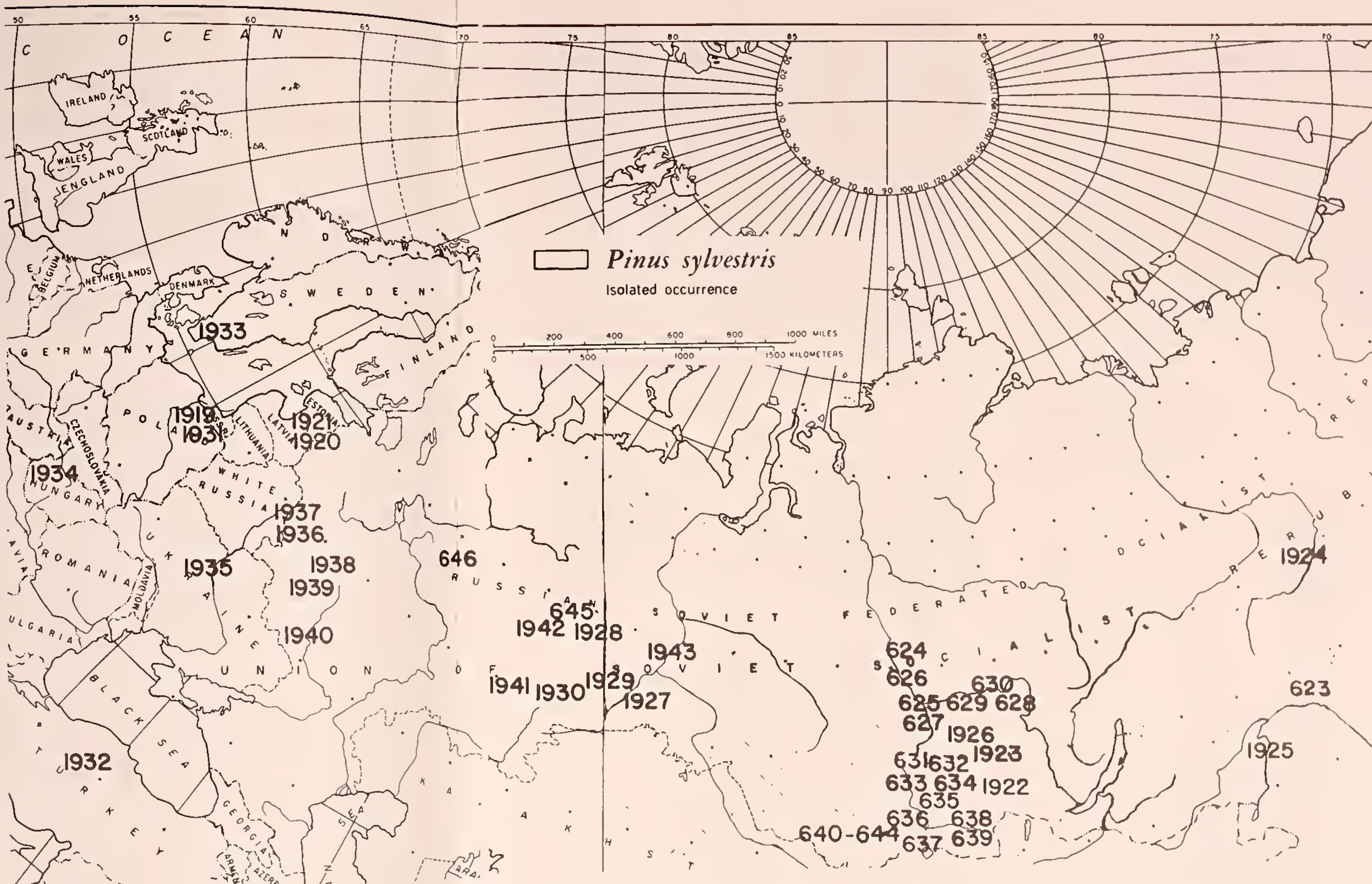
Trials 1 and 2 were separated by no more than 50 m. The soil at both trials is primarily an Aylmer-Bantry fine sand and is classified by the USDA, SCS as windbreak suitability class 10 because of its droughtiness and severe soil-blowing hazard. Site preparation consisted of plowing and disking a year prior to, and immediately before, planting.

Cultural Treatments

The ponderosa pine filler trees were removed from trial 1 in 1973, and the study trees were pruned to a height of 1.8 m in 1975. Trial 2 plots were thinned to two-tree plots in 1973 and to one-tree plots in 1979. Trees retained were pruned to a height of 1.8 m in 1979.

Figure 1.—Natural distribution of Scots pine and the location of the seed sources tested (see *Map 32, Critchfield and Little, 1966*).

Origin number	Latitude °N	Longitude °E	Geographic variety
U.S.S.R.--FAR EASTERN SIBERIA			
623	54.00	124.00	*mongolica*[1]
1924	60.75	131.67	*mongolica*
1925	52.33	117.67	*mongolica*
U.S.S.R.--NORTHERN SIBERIA[2]			
624	60.25	90.00	*lapponica*[1] *orientalis*[3]
626	60.25	90.00	*lapponica orientalis*
U.S.S.R.--CENTRAL SIBERIA, MIDDLE YENESEI RIVER			
625	58.50	92.00	*eniseensis*[3]
627	57.50	92.00	*eniseensis*
628	57.00	95.00	*eniseensis*
629	57.00	93.00	*eniseensis*
630	58.50	96.00	*eniseensis*
631	56.00	91.00	*eniseensis*
632	55.25	92.00	*eniseensis*
1923	56.00	95.00	*eniseensis*
1926	56.67	96.36	*eniseensis*
U.S.S.R.--SOUTH CENTRAL SIBERIA, SOUTHERN YENESEI RIVER			
1922	54.03	94.03	*eniseensis*
633	54.25	91.00	*eniseensis*
634	54.25	93.00	*eniseensis*
635	53.75	92.00	*eniseensis*
636	53.00	90.50	*eniseensis*
637	52.75	90.00	*eniseensis*
638	52.00	93.75	*eniseensis*
639	51.50	93.00	*eniseensis*
U.S.S.R.--SOUTHERN SIBERIA, ALTAI MOUNTAINS[2]			
640	52.00	84.00	*altaica*[1]
641	52.00	84.00	*altaica*
642	52.00	84.00	*altaica*
643	52.00	84.00	*altaica*
644	52.00	84.00	*altaica*
U.S.S.R.--EAST URAL MOUNTAINS			
1927	56.83	65.02	*uralensis*[1]
1928	58.83	60.83	*uralensis*
1929	56.92	63.25	*uralensis*
1930	56.85	61.38	*uralensis*
1943	58.00	68.00	*uralensis*
U.S.S.R.--WEST URAL MOUNTAINS			
645	59.50	57.50	*uralensis*
646	58.00	45.00	*uralensis*
1941	55.00	57.00	*uralensis*
1942	58.00	57.00	*uralensis*



Origin number	Latitude °N	Longitude °E	Geographic variety
U.S.S.R.--CENTRAL RUSSIA			
1935	50.00	30.00	*balcanica*[3]
1936	54.00	32.00	*balcanica*
1937	54.50	32.00	*balcanica*
1938	54.00	36.00	*balcanica*
1939	53.00	37.00	*balcanica*
1940	52.00	39.00	*balcanica*

Origin number	Latitude °N	Longitude °E	Geographic variety
U.S.S.R.--LATVIA			
1920	57.50	25.83	*rigensis*[1]
1921	57.67	26.33	*rigensis*
NORTHERN POLAND			
1919	53.83	20.45	*polonica*[1]
1931	53.72	20.45	*polonica*
SOUTHERN SWEDEN			
1933	55.87	14.0B	*septentrionalis*[1]

Origin number	Latitude °N	Longitude °E	Geographic variety
WESTERN HUNGARY			
1934	47.68	16.58	*pannonica*[1]
TURKEY			
1932	40.50	32.67	*armena*[1]

[1]Wright et al. (1966).
[2]From different sites and age classes.
[3]Pravdin (1969).

Assessment

Survival (SURV), and total height (HT) were measured at the end of years 1, 2, 5, 10, 20 (trial 2), and 22 (trial 1). Periodic annual height increment (PAI) was calculated as the average annual height increment over the life of the plantation. Because of the thinnings in 1973 and 1979, survival after the 10th growing season was used as the best estimate of survival for seed sources in trial 2. Winter foliage color (COLOR) was scored on a scale of 1.0 = yellow to 5.0 = blue-green. Crown density (CD) was scored on a scale of 1.0 = sparse to 3.0 = dense. Both COLOR and CD were scored after the end of the 10th growing season. Diameter at breast height (DBH) was measured after the 20th (trial 2) or 22nd (trial 1) growing season.

Analysis of Data

Differences in survival percentages among seed sources were analyzed by a chi-square test. Seed source differences in HT, DBH, and PAI were analyzed with SAS's General Linear Models (GLM) procedure (Statistical Analysis System, SAS Institute Inc., Cary, NC). All means were compared using Tukey's w-procedure. Simple Pearson correlations among variables were calculated using SAS's CORR procedure. Winter foliage color and crown density were analyzed with SAS's categorical modeling procedure (CATMOD).

The influence of each seed source's latitude (LAT) and longitude (LONG) on SURV, HT, PAI, CD, and COLOR was examined with multiple regression analyses using SAS's REG procedure.

Table 1.—Performance of 33 Scots pine seed sources in trial 1.

Variety[1]	Source			PERF	CD[2]	COLOR[3]	SURV[4]	DBH	PAI	HT[5]
	No.	Lat.	Long.							
		°N	°E	------- score	-------		%	cm	cm	m
balcanica	1939	53	37	367	1.9	2.7	95.8 a	24.1	56.2	11.7 a
balcanica	1938	54	36	359	1.8	2.7	95.8 a	23.2	59.5	11.5 ab
uralensis	1941	55	53	380	2.1	2.8	100.0 a	23.6	57.7	11.5 ab
balcanica	1936	54	32	374	2.1	3.0	87.5 a	22.9	58.8	11.5 ab
balcanica	1940	52	39	366	1.9	2.6	100.0 a	25.0	54.7	11.5 ab
altaica	641	52	84	353	2.1	2.2	87.5 a	24.1	59.8	11.4 abc
balcanica	1935	50	30	374	2.1	2.7	95.8 a	23.5	57.2	11.4 abc
altaica	644	52	84	365	2.2	2.0	100.0 a	24.6	56.4	11.2 abcd
altaica	640	52	84	347	1.9	2.1	95.8 a	24.0	57.9	11.2 abcd
uralensis	1942	58	57	378	2.4	2.3	100.0 a	21.3	58.8	11.0 abcde
rossica	646	58	45	360	2.2	2.3	91.7 a	20.9	60.3	10.9 abcdef
altaica	642	52	84	355	2.1	2.1	95.8 a	23.1	54.5	10.9 abcdef
krasnoyarsk	636	53	90	366	2.4	2.0	95.8 a	22.4	57.5	10.9 abcdef
krasnoyarsk	633	54	91	371	2.5	1.9	100.0 a	22.0	57.5	10.9 abcdef
uralensis	645	60	58	343	2.1	2.0	87.5 a	20.7	59.6	10.8 abcdefg
altaica	643	52	84	344	1.8	2.1	100.0 a	23.3	57.3	10.8 abcdefg
balcanica	1937	54	32	358	2.1	2.2	100.0 a	20.4	58.3	10.8 abcdefg
krasnoyarsk	632	55	92	357	2.4	1.9	91.7 a	21.6	57.5	10.7 abcdefg
krasnoyarsk	637	53	90	370	2.4	2.5	91.7 a	21.6	56.1	10.7 abcdefg
mongolica	629	57	93	339	2.1	1.5	95.8 a	21.0	57.9	10.6 abcdefg
krasnoyarsk	634	54	93	347	2.2	2.0	87.5 a	20.5	57.0	10.6 abcdefg
uralensis	1943	58	68	364	2.4	2.0	100.0 a	20.0	56.0	10.5 abcdefg
mongolica	627	58	92	324	2.0	1.6	87.5 a	19.3	59.6	10.5 abcdefg
krasnoyarsk	638	52	94	340	2.1	1.8	95.8 a	20.2	58.3	10.3 bcdefgh
krasnoyarsk	639	52	93	363	2.4	1.9	100.0 a	21.2	54.6	10.2 bcdefgh
krasnoyarsk	635	54	92	354	2.4	2.0	91.7 a	20.6	55.7	10.2 bcdefgh
mongolica	628	57	95	343	2.2	1.6	100.0 a	19.3	57.1	10.2 bcdefgh
mongolica	630	58	96	348	2.2	2.0	95.8 a	18.0	57.2	10.1 defgh
mongolica	625	58	92	340	2.1	1.6	100.0 a	19.3	55.6	10.0 defgh
jacutensis	623	54	124	323	2.0	1.6	91.7 a	19.1	54.2	9.8 efgh
mongolica	631	56	91	322	2.2	1.7	83.3 a	18.4	57.4	9.7 efgh
mongolica	626	60	90	274	1.8	1.6	62.5 b	16.0	52.3	8.9 h
mongolica	624	60	90	234	1.5	1.1	62.5 b	10.9	47.0	7.2 i
Mean				350	2.1	2.1	92.9	21.3	57.0	10.7
S.E.					0.02	0.03	1.61	0.15	0.28	0.05
N					736	739	33	736	736	736

[1]*Varieties as described by Ruby and Wright (1976) except jacutensis, balcanica, and lapponica-orientalis, which were described by Pravdin (1969).*

[2]*Crown density score: 1.0 = sparse, 2.0 = medium, 3.0 = dense.*

[3]*Winter foliage color score: 1.0 = yellow to 5.0 = blue-green.*

[4]*Means not followed by the same letter designate seed sources having significantly different survival probabilities as revealed by the chi-square test ($p = 0.05$).*

[5]*Means followed by the same letter were not significantly different when subjected to Tukey's w-procedure ($p = 0.05$).*

As a means of comparing the overall performance of the seed sources, and the varieties they represented, the relative performance of each seed source was computed by expressing the mean for each seed source as a percentage of the plantation mean (PCPM) for SURV, PAI, CD, and COLOR. A measure of a seed source's value as a component of a windbreak was defined as the sum of the PCPM's for SURV, PAI, CD, and one-half the PCPM for COLOR. Because winter foliage color is not critical to a tree's function in a windbreak and is more of an aesthetic value, its score was reduced in importance.

Results

Each of the 49 seed sources was classified into one of 11 geographic varieties as described by Pravdin (1969) or Ruby and Wright (1976). Performance of the 49 seed sources is shown in tables 1 and 2.

Survival

Survival at both trials was excellent, averaging over 92%. Only two seed sources at each trial had survival rates less than 80%. In trial 1, those seed sources were 624 and 626 from 60° north latitude, the most northern of any seed sources in either trial. In trial 2, two seed sources surviving poorly were 1924 and 1934, with 1934 the most westerly seed source and 1924 the most easterly seed source in either trial.

Significant correlations of latitude and longitude with SURV, HT, DBH, CD, or COLOR were primarily the result of these 4 seed sources performing much differently from the other 45 seed sources.

Height

Differences in height growth among the origins were highly significant. At trial 1, the tallest seed source, 1939, averaged over 56 cm of PAI (table 1). Seed source 646, while not the tallest, had the greatest PAI (60.3 cm). There were few significant differences among the faster growing seed sources, but seed sources 624 and 626 were significantly slower growing than the others. At trial 2, seed sources 1924 and 1932 were slower growing than any of the others, while the 11 fastest growing seed sources did not differ significantly. Seed source 1931 was the fastest growing seed source in both trials, averaging over 64 cm per year. Overall, trees from the rigensis variety had the greatest PAI, and were followed closely by the *rossica*, *balcanica*, *ura*lensis, and *altai* varieties. The *pannonica* variety from Hungary and the *lapponica*-*orientalis* variety from northern Siberia, were the slowest growing varieties. Latitude and longitude were negatively correlated with HT in both trials, and multiple regression analyses that included LAT, LONG, LATSQ (LAT squared), LONGSQ (LONG squared) and LATLO (LAT X LONG) accounted for 71% of the height variation at trial 1, and 92% at trial 2 (table 3). The correlation of PAI with latitude or longitude was not signifi-

Table 2.—Performance of 16 Scots pine seed sources in trial 2.

Variety[1]	Source No.	Source Lat.	Source Long.	PERF	CD[2]	COLOR[3]	SURV[4]	DBH	PAI	HT[5]
		°N	°E	score	score	score	%	cm	cm	m
rigensis	1931	54	20	368	1.7	3.4	92.5 a	21.7	63.2	11.2 *a*
ralensis	1928	59	61	360	1.8	2.6	100.0 *a*	19.7	64.6	10.8 *a*b
rigensis	1921	58	26	375	1.8	3.5	97.5 *a*	18.8	61.9	10.7 *a*bc
rigensis	1920	58	26	367	1.7	3.3	97.5 *a*	19.7	60.0	10.7 *a*bc
rigensis	1919	54	20	369	1.8	3.3	97.5 a	18.4	59.4	10.6 *a*bcd
ralensis	1930	57	61	355	1.8	2.8	92.5 *a*	19.4	58.8	10.5 *a*bcd
rigensis	1933	56	14	371	1.8	3.6	95.5 *a*	18.9	58.3	10.5 *a*bcd
ralensis	1927	57	65	355	1.8	2.6	97.5 *a*	18.7	56.0	10.3 *a*bcd
krasnoyarsk	1922	54	94	363	1.9	2.9	97.5 *a*	18.5	59.8	10.1 *a*bcd
mongolica	1923	56	95	356	1.9	2.8	95.0 *a*	19.5	56.6	10.2 *a*bcd
ralensis	1929	57	63	349	1.8	2.7	95.0 *a*	17.1	54.7	9.9 *a*bcd
mongolica	1926	57	96	338	1.7	2.5	95.0 a	14.6	56.0	9.5 bcd
jacutensis	1925	52	118	350	1.9	2.7	95.0 *a*	16.9	55.9	9.4 cd
pannonica	1934	48	17	316	1.6	3.5	67.5 b	15.2	53.2	9.1 de
armena	1932	40	33	335	1.7	4.2	82.5 a	14.0	51.6	7.8 ef
lap-orient	1924	61	132	260	1.6	1.6	67.5 b	10.2	52.2	7.1 f
Plantation means				350	1.9	3.1	91.6	17.8	57.9	10.0
S.E.					0.03	0.06	2.54	0.31	0.95	0.11
N					160	160	16	139	139	139

[1]*Varieties as described by Ruby and Wright (1976) except jacutensis, balcanica, and lapponica-orientalis, which were described by Pravdin (1969).*

[2]*Crown density score: 1.0 = sparse, 2.0 = medium, 3.0 = dense.*

[3]*Winter foliage color score: 1.0 = yellow to 5.0 = blue-green.*

[4]*Values not followed by the same letter designate seed sources having significantly different survival probabilities as revealed by the chi-square test of the hypothesis that the survival probabilities of the seed sources were the same (p = 0.05).*

[5]*Means followed by the same letter were not significantly different when subjected to Tukey's w-procedure (p = 0.05).*

Table 3.—Multiple regression analysis of 49 Scots pine seed sources tested in North Dakota.[1]

Var.	Trial	R^2	Par.	LAT	LATSQ	LONG	LONSQ	LATLO	INTERC	Cp
SURV	1	0.397	r	−0.468	−0.477	−0.190	−0.188	−0.268		
			RC	54.443	−50.346	ns	ns	−0.117	−1369.7	3.0
			p	0.012	0.010	ns	ns	0.255	0.021	
	2	0.864	r	0.327	0.305	−0.100	−0.231	−0.118		
			RC	–	2.935	309.7	−2.392	−5.082	−0.9	4.6
			p	–	0.001	0.001	0.037	0.001	0.943	
HT	1	0.710	r	−0.574	−0.581	−0.541	−0.541	−0.624		
			RC	4.720	−4.409	2.391	−0.031	ns	−115.2	4.4
			p	0.002	0.001	0.289	0.067	ns	0.004	
	2	0.921	r	0.354	0.317	−0.452	−0.538	−0.442		
			RC	1.278	−1.044	14.870	−0.025	−0.237	−28.3	6.0
			p	0.012	0.038	0.013	0.022	0.034	0.016	
PAI	1	0.394	r	−0.093	−0.103	−0.311	−0.315	−0.332		
			RC	0.159	−0.137	0.520	ns	−0.010	−4.0	4.1
			p	0.010	0.016	0.50	ns	0.125	0.016	
	2	0.562	r	0.255	0.246	−0.387	−0.444	−0.377		
			RC	−0.033	0.042	0.828	ns	−0.016	1.12	4.1
			p	0.299	0.204	0.040	ns	0.031	0.141	
CD	1	0.238	r	−0.109	−0.118	0.161	0.130	0.123		
			RC	1.369	−1.248	1.541	0.010	ns	−35.8	5.0
			p	0.025	0.024	0.116	0.145	ns	0.033	
	2	0.873	r	0.168	0.129	0.127	0.022	0.078		
			RC	0.090	−0.066	0.293	−0.001	−0.049	−1.2	6.0
			p	0.087	0.213	0.001	0.224	0.001	0.302	
COLOR	1	0.774	r	−0.499	−0.501	−0.764	−0.746	−0.821		
			RC	1.000	0.957	−1.250	–	–	−23.0	2.5
			p	0.091	0.074	0.001	–	–	0.157	
	2	0.949	r	−0.703	−0.711	−0.829	−0.804	−0.875		
			RC	−0.344	0.340	5.946	0.005	−0.138	12.3	6.0
			p	0.084	0.102	0.019	0.222	0.008	0.015	

[1]*Parameters: r is the simple Pearson correlation for each independent variable;*
R^2 is multiple correlation coefficient for the regression equation having the best fit as determined by Mallows' Cp statistic. Best model indicated when Cp approaches the number of independent variables in the model;
RC is the partial regression coefficient for each independent variable – the values for LONG, LATSQ, LONGSQ, and LATLO are times 10;
$p > t$ is the probability of getting a larger value of t if the parameter is truly equal to zero. Very small values lead to the conclusion that the independent variable contributes significantly to the model. Values less than 0.001 are rounded to 0.001.

cant (fig. 2), however, multiple regression analyses revealed a significant relationship of LAT, LONG, LATSQ, and LATLO which accounted for 39% of the variation in trial 1 and 56% of the variation in trial 2 (table 3).

Diameter at Breast Height

Because of the high correlation between height and DBH at both trials ($r = 0.95$), differences among seed sources in DBH paralleled their differences in height (tables 1 and 2). Seed sources 624 and 626 at trial 1 and seed source 1924 at trial 2 were significantly smaller than other seed sources in their respective plantations. Correlations with other variables were similar to those for height.

Crown Density

Differences among the seed sources in response probabilities for crown density were small and lacked any discernible pattern associated with seed source. At trial 1, seed source 632 had the highest proportion of trees scored as dense and seed source 624 had the highest proportion of trees scored as sparse. There were only minor differences in the response profiles among seed sources at trial 2. Multiple regression analyses involving combinations of latitude and longitude could only account for 24% of the variation in trial 1, but accounted for 87% in trial 2. LONG and LATLONG had the most influence on crown density in trial 2 (table 3). When analyzed on the basis of varieties, the *lapponica-orientalis* variety had a higher proportion of trees scored as having sparse crowns (table 4). The *krasnoyarsk* variety had

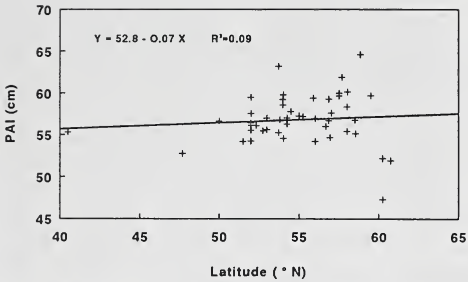


Figure 2a.—Relationship between PAI and the latitude of the seed source.

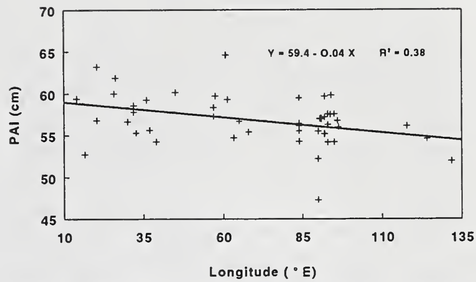


Figure 2b.—Relationship between PAI and the longitude of the seed source.

Table 4. Performance of eleven Scots pine varieties tested in North Dakota.

Geographic area	Variety	SURV	HT	DBH	PAI	CD[1]	COLOR[2]	PERF
		%	*m*	*cm*	*cm*	---------	*score* ---------	
E. Europe	*rigensis*	96.1	10.8	19.5	60.8	1.8 ab	3.4 e	370
Central Russia	*balcanica*	95.8	11.4	23.2	57.4	3.7 ab	2.0 d	367
Ural Mountains	*uralensis*	97.1	10.7	20.1	58.2	2.5 c	2.4 c	361
Altai Mountains	*altaica*	95.8	11.1	23.8	57.1	3.1 c	2.0 b	360
N.W. U.S.S.R.	*rossica*	91.7	10.9	20.9	60.3	3.2 c	2.2 bc	359
S. Yenisey River	*krasnoyarsk*	95.6	10.5	21.0	56.9	2.8 c	2.4 b	353
Eastern U.S.S.R.	*jacutensis*	93.4	9.6	18.0	54.7	1.8 abc	2.3 b	337
Turkey	*armena*	82.5	7.8	14.0	51.6	1.7 ab	4.2 f	335
Yenisey River	*mongolica*	87.7	9.7	17.6	56.0	2.2 ab	2.1 a	322
W. Hungary	*pannonica*	67.5	9.1	15.2	53.2	1.6 ab	3.5 e	316
N. Siberia	*lap-orient*	67.5	7.1	10.2	52.2	1.6 a	1.6 a	260
Overall mean		92.5	10.6	20.7	57.1	2.1	2.3	350
S.E.		1.35	0.05	0.14	0.22	0.02	0.03	
N		49	875	875	875	896	899	

[1] *Varieties designated by the same letter have the same response probabilities for crown density scores as determined by the chi-square test with $p < 0.01$.*

[2] *Varieties designated by the same letter have the same response probabilities for foliage color scores as determined by the chi-square test with $p < 0.01$.*

the highest proportion of trees scored as having dense crowns.

Winter Foliage Color

Winter foliage color varied significantly among the varieties (table 4). At trial 2, 80% of the trees from the *armena* variety (seed source 1932) were scored blue-green and 20% blue. Seventy percent of the trees from the *lapponica-orientalis* variety (seed source 1924) were scored yellow-green and 30% yellow. At trial 1, seed source 624 had more yellow trees and seed source 1936 had more blue-green or blue trees than any other seed source. Winter foliage color was negatively correlated with latitude and longitude at both trials (table 3). Multiple regression analyses of latitude and longitude accounted for 77% of the variation in COLOR in trial 1 and 95% in trial 2 (table 3). Varieties from the southwestern and western areas of the region sampled (*armena*, *pannonica*, and *rigensis*) possessed winter foliage with a blue-green color, while seed sources from the northeastern area (variety lapponica-orientalis) were very yellow (fig. 3).

Performance Scores

The PCPM'S calculated by seed source for each variable were also summed by seed source to give a composite score that is a measure of a seed source's value as a component of a windbreak. The composite scores for seed sources were summed by varieties and are shown in table 4. A seed source or variety that was average for all traits would score 350. Seed sources from south of latitude 54° north and west of longitude 94° east had above average scores (fig. 4).

Juvenile-Mature Correlations

The simple correlations between total height at ages 5, 10, and 20 (trial 2) or 22 (trial 1) are shown in table 5. All correlations were significant at $p < 0.01$. These correlations may be interpreted to mean that at least 9

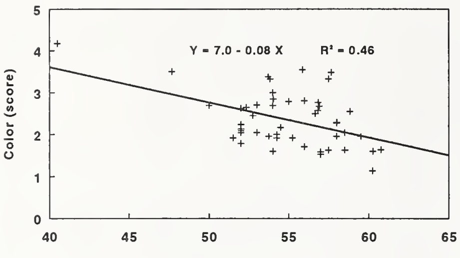


Figure 3a.—Relationship between COLOR and the latitude of the seed source.

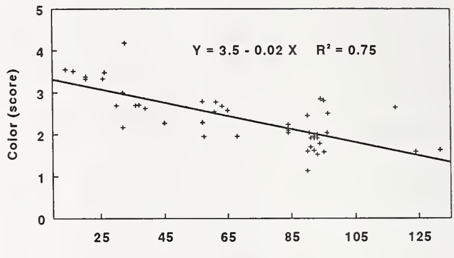


Figure 3b.—Relationship between COLOR and the longitude of the seed source.

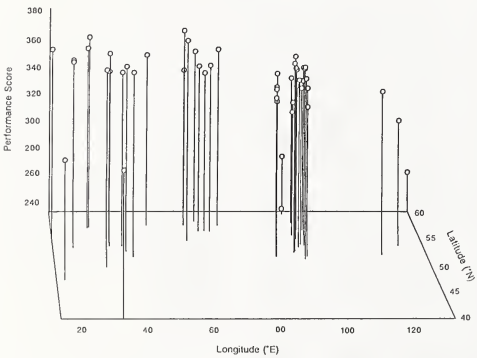


Figure 4.—Performance scores of 49 seed sources of Scots pine.

Table 5. Juvenile-mature correlations for total height.[1]

	Interval (years)[2]		
Trial	5 & 10	10 & 20 (22)	5 & 20 (22)
1	0.96	0.95	0.87
2	0.98	0.96	0.92

[1]*r = simple Pearson correlation coefficient. Based on seed source means averaged across replications. All values are significant ($p<0.001$).*
[2]*End of interval is 22 years for trial 1 and 20 years for 2.*

of the seed sources ranking in the top 10 at the end of the period could have been predicted to be among the top 10 seed sources based on their performance at the beginning of the period.

Discussion

In general, seed sources from the western region of the area sampled (varieties *rigensis* and *balcanica*), grew taller, were larger in diameter, and had greener winter foliage. An exception was seed source 1932 from Turkey, whose performance for all traits, except winter foliage color, was below average. Seed source 1932's winter foliage color averaged 40% greener than the plantation average. Seed source 1933 from southern Sweden, also scored above average for winter foliage color and for all other traits. Seed source 1933 would be a good choice for Christmas tree culture in the northern Great Plains.

In terms of suitability for windbreaks, seed source 1941 from the western Ural Mountains achieved the highest score. Excellent survival, growth rate, and winter foliage color were its greatest attributes and only crown density scored below average. Seed source 633 from the southern Yenisei River exhibited the best crown density among the top 10 seed sources and was average or above for all other traits.

Verification of Pravdin's (1969) or Ruby and Wright's (1976) classification of these 49 seed sources into distinct geographic varieties was not possible for all 11 varieties because of inadequate samples from 5 of the varieties. However, the analysis of variance and categorical modeling revealed fairly distinct differences among the six remaining varieties. The *rigensis* variety separated quite distinctly from all other varieties. Considerable within-variety variation and overlap was evident between the *balcanica* and *uralensis* varieties. Both the *mongolica* and *krasnoyarsk* varieties were quite variable among seed sources but fell into fairly distinct, adjacent groups. Seed sources from the Altai Mountains variety grouped together and were distinct from all other varieties.

Considerable within-variety variation and overlap between the *balcanica* and *uralensis* varieties may be attributable to the location of many of these seed sources in isolated or discontinuous populations at the fringes of the major populations. Such populations may have undergone considerable genetic drift. The considerable within-variety variation in the *krasnoyarsk* and *mongolica* varieties suggests that additional varieties may exist beyond those identified by Ruby and Wright (1976) and Pravdin (1969). Both studies lacked sufficient samples from seed sources east of about 30° east latitude. Ruby and Wright recognized that additional varieties probably existed in unsampled areas.

Among the 11 varieties represented in this study, the *rigensis* variety from Latvia and southern Sweden

achieved the highest score. Above average survival, growth rate, and winter foliage color were its strengths. The *balcanica* variety from central Russia performed nearly as well, with crown density only slightly below average. The *uralensis* variety supplied the highest scoring seed source and, as a whole, this variety ranked third best, with winter foliage color the only trait ranking below average. Excellent crown density was the strength of the *krasnoyarsk* variety. The *lapponica-orientalis* variety from northern Siberia performed the poorest. Seed sources from this variety performed well below average for all traits, with diameter and winter foliage color its major weaknesses.

Total height at ages 5 and 10 was highly correlated with mature performance. At least 9 of the top 10 performing seed sources could have been predicted on the basis of their height at age 5 or 10. Strong relationships of this type suggest that early evaluation of Scots pine provenance tests and progeny tests will be possible with little loss of reliability.

Conclusions

The results of this provenance study show that Scots pine is well suited for planting in the northern Great Plains if planting stock from the proper seed source is used. Seed sources from 20° to 57° east longitude and 50° to 58° north latitude should produce planting stock suitable for windbreaks and other conservation plantings. If seed can be obtained from specific geographic locations, natural stands in the following regions would be good choices as a source of seed for the production of windbreak planting stock:

Seed source	Lat. °N	Long. °E	Region or Province
1941	55	57	Bashkir A.S.S.R. in the western Ural Mountains
1942	58	57	Perm province in the western Ural Mountains
1921	58	26	Estonian S.S.R. in European Russia
1935	50	30	Kiev province in the Ukranian S.S.R.
1936	54	32	Smolensk province southwest of Moscow

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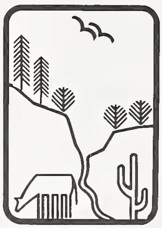
Rocky
Mountains



Southwest

Great
Plains

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